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INVESTIGATION OF ABUNDANCE AND SPATIAL DISTRIBUTION OF MARINE DEBRIS ON GHANAIAN URBAN COASTAL BEACHES

Kofi Adu-Boahen[1]

[1]University of Education, Department of Geography Education, Winneba, Ghana, P.O Box 25, Winneba, Ghana
*Corresponding author: kadu-boahen@uew.edu.gh

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Abstract

Marine debris has been identified as a form of pollution for more than half a century, and it is a major concern for the general public due to its detrimental effects on the environment and human health. The accumulation of marine debris not only affects the aesthetic appeal of our oceans but also poses a significant threat to safety. The impact of marine debris on the tourism industry, especially the eco-tourism sector, is a growing concern both locally and globally. The objective of this study was to conduct a comprehensive assessment of marine debris on three beaches of Ghana along the Gulf of Guinea. It sought to survey the spatiotemporal changes in the concentration of marine debris, quantify the perceptions of locals and beach users of marine debris, examine the citizen science perspectives on marine debris and finally analyse the effects of marine debris on coastal resources. The study employed a shoreline debris survey and citizen science approach to achieve this objective. Content analysis in NVivo was deployed to analyze transcriptions from the interviews. A standing stock beach survey was used to survey debris in 100 m^2 quadrants for 30 occasions each for the three studied beaches at 12-day intervals, which spanned one year. Debris was classified and quantified according to the NOAA classification scheme for marine debris. The quantitative data generated were analyzed in SPSS 23.0 to establish debris abundance and spatiotemporal differences. Results revealed that plastics are the dominant debris type, accounting for 52% of the total debris surveyed, which was confirmed by the citizen science approach. Biriwa Beach had a minor debris abundance, statistically different from Abandze and Anomabo. The paper found significant seasonal differences in the concentration and spatial distribution of all debris types except for plastics and processed lumber. Respondents acknowledged the effects of marine debris on humans and the environment. The study recommends making adequate waste management infrastructure available in the area. NGOs and the Municipal Assembly should educate residents on effective mass participation in waste management practices to curb debris accumulation.

Keywords: marine debris, macroplastic, standing stock survey, abundance and distribution, citizen science

INTRODUCTION

Whether unintentionally or intentionally, human activities lead to the formation of marine litter (Galgani et al., 2021). For researchers to quantify and complete the worldwide catalogue of marine plastics, which provides essential data for mitigation or policy interventions, it is imperative to have a greater awareness of how plastic trash is transported from coastal and marine sources (Van Sebille et al., 2020). Aquatic systems play a crucial role in tying distant locations together by moving goods across great distances and, in the case of oceans, even between continents (Boadu et al., 2021). This comprises solid materials and particle matter fluctuating on or near the surface of water bodies or suspended in the water column in addition to transferring heat and chemical substances that influence the planet's climate (Thushari and Senevirathna, 2020). Although it is a known environmental issue, waste from the ocean is becoming more widespread. A study by Borrelle et al. (2020) estimated that in 2016, as much as 23 million metric tons of plastic waste entered aquatic ecosystems from land around the world. Several authors (Walker and Xanthos, 2018; Barnes et al., 2009; Derraik, 2002) consider marine debris as an issue that transcends national borders and is persistent throughout the world. According to the OSPAR Commission (2007), roughly 6.4 million tons of debris are added to the seas yearly, or about 8 million items daily. According to Jambeck et al. (2015), 4.8–12.7 million metric tons entered the world's waters in 2010 alone. Borrelle et al. (2020) demonstrated an atmosphere of increasing accumulation.

According to Abdel-Shafy and Mansour (2018), pollution control and garbage management are significant problems in most coastal neighborhoods due to a shortage of land and resources for properly disposing of waste, population growth, expansion of the tourism sector, and an upsurge in the importation of potentially dangerous and contaminating materials. According to the OSPAR Commission (2007), marine debris consists of objects that slowly deteriorate and can be found on the seabed, stranded on beaches, or drifting in the water column. The United Nations Environment Program defines marine debris as: "any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment. Marine debris/litter consists of items that have been made or used by people and deliberately discarded into the sea or rivers or on beaches; brought indirectly to the sea with rivers, sewage, stormwater or winds; accidentally lost, including material lost at sea in bad weather (fishing gear, cargo); or deliberately left by people on beaches and shores" (UNEP, 2017). Besides, numerous shipwrecks and discarded weapons, vessels, and other objects left on the ocean floor have been accidentally lost or purposefully drowned during a battle. Challenges to the marine ecosystem are posed by anthropogenic activities, which enhance the quantity of organic and synthetic materials entering the ocean. Boyer et al. (2013) claim that almost all artificial materials have the potential to become marine debris if not appropriately treated. According to Meijer et al. (2021) and Weiss et al. (2021), rivers are the primary route for uncontrolled plastic waste to enter the oceans. About 82.53 % of the debris in the Black Sea is of plastic material; the Indian Ocean harbours debris with 69.99% plastic composition; in the North Sea, 65.79% is identified; with the Wider Caribbean and the Pacific Ocean featuring 64.27% and 62.95% respectively (Savuca et al., 2022; Zorrilla et al., 2021). The least is reported for Central Europe, where a 42.79% plastic composition has been established, and there is no direct connection to seas (UNEP, 2009).

One of the most harmful and enduring marine contaminants is marine debris. According to the UNEP Global Programme of Action for Protection of the Marine Environment from Land-Based Activities (Allsopp et al., 2008), one of nine pollution classifications must be addressed. Marine debris has been researched as an imminent danger to delicate habitats, fisheries, tourism, and human health. It is well acknowledged that marine debris harms the ecosystem of the oceans. The debris affects the marine environment from beaches to the sea floor, which impacts the coastal and marine ecosystem, particularly the benthic habitat (Williams et al., 2005). As a consequence of marine debris, hundreds of marine species have been injured, vessel movement has been impeded, ocean habitats have deteriorated, millions of dollars in lost fishing and tourism revenue have been incurred, and human health and safety have been put at risk (Stickel et al., 2012). According to Ebbesmeyer et al. (2012), if wholehearted prevention cannot be accomplished, practical actions must be implemented to reduce the amount of trash disposed of in coastal areas and oceans each year. It has been determined that cleaning up would only meaningfully safeguard marine animals and ecosystems if something is done to reduce the flow of waste into the maritime environment. This is to express that clean-up could have an impact on debris transport into the oceans. At various levels of management, there are numerous initiatives to minimise marine debris, including public policies, education initiatives, surveillance of marine plastic, and partnerships between international organisations, the private sector, and non-governmental organisations (Walker et al., 2021). The significance and necessity of the global observing system are supported by the international scope and escalating severity of the repercussions.

Ghana has a 550 km-long and productive coastline that borders the Gulf of Guinea. This coastal zone is highly profitable and provides diverse ecological and economic assets. Several studies, including those by Cózar et al. (2014) and Poeta et al. (2014), have emphasised the prevalence of litter deposition at or near the ocean's surface. According to Nunoo and Quayson (2003), expressions detect litter accumulation on Ghanaian beaches, consistent with many other regional investigations. Despite superannuation, scientists have knowledge gaps in our understanding of the numbers of debris in the marine environment (Thiel et al., 2003; Pichel et al., 2007). According to Walker et al. (2021), an urgent requirement is to build suitable local, national, and regional marine debris databases for data sharing with the rest of the world. Walker et al. (2021) asserted that a solid database for managing and reporting marine debris could help gather data for particular parameters and impacts on environments or economies worldwide, increasing harmonisation and comparison.

Similarly, Xanthos and Walker (2017), Schnurr et al. (2018), and Martín-Lara et al. (2021) argued that a robust debris monitoring platform could help policymakers to decrease debris sources and improve the efficiency of reduction and policy initiatives by way of improved waste tracking, citizen science, and restoration of the environment. Monitoring systems incorporating data collected by remote sensing (Salgado-Hernanz et al., 2021) or citizen science (Bergmann et al., 2017; Fauziah et al., 2021) either present or are being created to comprehend better knowledge of marine debris and the ways its control. The current study focuses on a ground-based sampling of marine debris employing NOAA methodologies to obtain information regarding the quantities of marine trash built up on Ghanaian coastlines. The paper, therefore, was guided by three interconnected objectives, which were (1) to survey the spatiotemporal changes in the concentration of marine debris, (2) to quantify the perceptions of locals and beach users of marine debris, examine the citizen science perspectives on marine debris, and finally (3) to analyse the effects of marine debris on coastal resources.

The study's findings will improve our understanding of the type, quantity, and spatial distribution of marine debris along the Gulf of Guinea, which will aid in mitigating the socioeconomic implications of debris accumulation in the selected areas. This paper also highlights the various effects of marine litter and plastics on the environment and marine organisms. The study emphasizes the need for further research to understand better the harmful effects caused by any material on all levels of biological organization. It also encourages a discussion forum to understand better the potential impact of marine litter on the marine/estuarine environment and communities. Additionally, the paper proposes new strategies for the prevention, mitigation, and monitoring of marine litter.

STUDY AREA

The study area is located on the Ghanaian coastline of the Gulf of Guinea in Ghana's Central Region, which is noted for its tourism potential. The study area includes three beaches: Abandze, Anomabo, and Biriwa (Fig. 1). The area is bounded in-between latitudes 5°10'00" N and 5°8'00" N and longitudes 1°10'00" W and 1°5'00" W.

The area studied is about 5.5 km^2. The communities are in the Mfantseman Municipality. The Municipality has a total population of 168,905, with females making up 53.8% (90,872) and males making up 46.2% (78,033), resulting in a sex ratio of 46:54 (Ghana Statistical Service, 2021). The population density of the area is 537.2/km^2, with an annual growth rate of 1.5%. In terms of education, there are 86 public basic schools and eight public Senior High schools in the Municipality. The performance of students in the 2021 BECE was 65.3%, which is an improvement over the 2020 performance of 52.9%. Additionally, there is one Theological Seminary School for the Assemblies of God, Southern Ghana section, located at Kormantse (Mfantseman Municipality Assembly, 2023). The terrain is predominantly flat and adorned with grass and scrub in general. Cretaceous-Eocene coastal sands with thin, pebbly sands line the beaches. Several rivers and streams drain the area, including the Nkasaku River, which flows into the Atufa lagoon in Saltpond, and the Aworaba River, which flows into the Etsi lagoon in Kormantse. Other lagoons with rivulets are the Eko near Anomabo, the Egya at Egyaa, and the Kwasinzema at Kormantse.

Because of its proximity to the Atlantic Ocean, the area experiences mild monthly mean temperatures ranging from 24° C to 28° C. The relative humidity of the air is around 70%. The region has two rainfall maximums, with peaks in May-June and October. Annual rainfall ranges between 900 and 1100 mm in the coastal savanna areas and 1100-1600 mm in the interior along the forest zone's boundary. December to February and July to early September are significantly drier periods than the rest of the year. Farming and fishing are the primary sources of revenue in the surrounding region, employing nearly 70% of the entire inhabitants.

The winds in the region are mostly influenced by the south-westerly monsoon, which is altered by the land and sea breezes in the coastal area. It is an area with a high-energy environment with wave height often exceeding 1 meter (Ly, 1980). At night, the wind speed is around 0.5 m/s, while it increases to 2.0 m/s during the day. On average, the winds blow towards the southwest direction with a speed of 3 m/s throughout the year in Ghana. The tides along the coast of Ghana are regular and semi-diurnal, which means they have two high tides and two low tides every day, with virtually the same phase across the coast. Tidal currents are generally low and do not have a significant impact on coastal processes except within tidal inlets. This is exactly the nature of the tides along the coastlines of the study areas. Ocean currents can occasionally turn to the southwest at depths below 40 m, with velocities ranging from 0.5 to 1.0 m/s and 0.05 to 1.02 m/s near the bottom (Binet et al., 1991). This phenomenon occurs mostly during the season of southwesterly winds, which is from June to October, and the currents maintain their highest velocities during this period. The study area is located on the central coastline of Ghana, which is the longest geomorphic region stretching from Cape Three Point to Prampram. The morphology of this region comprises rocky coasts with bays, sand barriers, and coastal lagoons (Armah et al., 2004).

Regarding waste collection and management, based on the standard figure of 0.5 kg/capita/day, the Mfantseman Municipal Assembly (2023) reported that the Municipality produces 72.2 metric tonnes of refuse daily. Unfortunately, many coastal communities in the Municipality suffer from indiscriminate defecation and waste disposal, which negatively affects public health and tourism. This issue stems from the fact that most houses in the area are built without proper household toilet facilities. The municipality faces environmental challenges such as insufficient skip and refuse containers, leading to indiscriminate refuse dumping and poor drainage systems in major settlements like Anomabo, Mankessim, and Abandze.

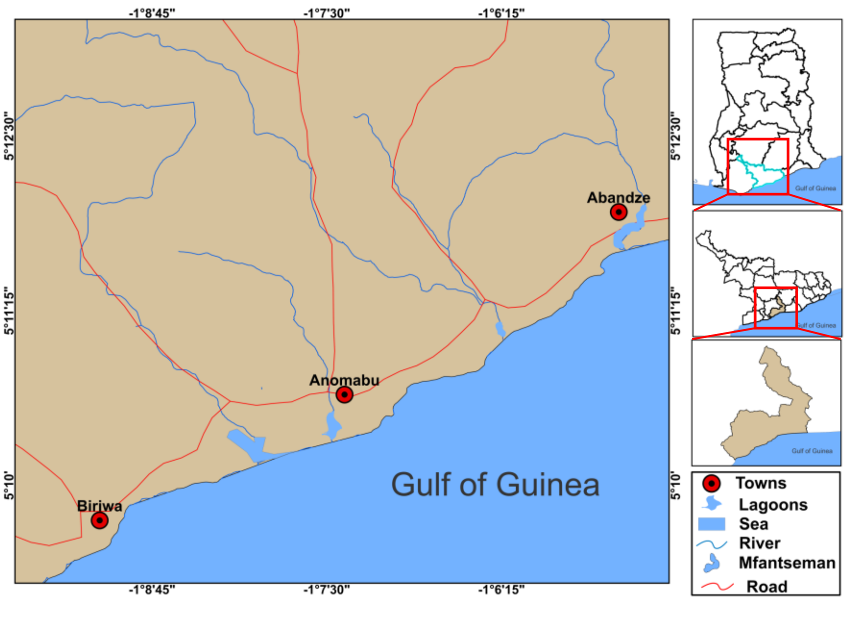

Fig.1 The study area covers three communities in the Central Coastline of Ghana, by the Atlantic Ocean

MATERIALS AND METHODS

The study is positioned in the positivist worldview because it provided the philosophical foundation for the conduct of the research. Positivist research aims to examine patterns and connections between social factors to facilitate accurate predictions about society and social change. According to positivists, this is best achieved through quantitative method (Creswell and Creswell, 2017).

Debris collection, classification, quantification and quality control

Beach litter was collected for one year between November 2021 and October 2022 at 12-day intervals; thus, litter was quantified in 30 days. This followed Sheavly and Register (2007), who averred that at least one standing stock survey should be followed once every 28±3 days. November to April was considered the dry season, while May to October was designated the wet season. Data were collected during field visits to the three studied beach sites in the Municipality on different days within the week. During each litter collection day, four surveys were conducted independently in each quadrant of the beach sites. This process was repeated in each study area visited during the week.

Surveys were carried out following the standing stock survey approach since the study was interested in measuring the density of debris on the beaches of the three study sites. Litter was collected using the quadrant (transect) walking pattern for marine debris shoreline survey (NOAA, 2012). Using conventional NOAA marine debris shoreline survey techniques, beach trash was gathered in a large 100 m^2 area, which was further divided into four quadrants perpendicular to the coastline (Opfer et al., 2012). The demarcated areas ran parallel to the sea between the low tide mark and the zone of emergent vegetation. During the study, four quadrants were laid out, each with a width of 5 m. The first transect covered a distance of 0–5 m, the second transect covered 15–20 m, the third transect covered 20–25 m, and the fourth transect covered 75–80 m. The waste material was further classified as plastics, metal, rubber, glass, clothing, and others based on the research conducted by (Opfer et al. 2012; NOAA 2012). The study did not consider organic matter due to its limited or insignificant presence. Only litter sizes larger than 3 cm were considered for beach litter, as the focus of the study did not include micro-objects (⩽3 cm).

Quality control

Producing accurate data requires laboratories to implement good field and laboratory procedures as part of a Quality Assurance/Quality Control (QA/QC) system. This involves selecting internationally validated methodologies for sampling and analysis, using reference materials (preferably certified reference materials), and participating in international intercomparison exercises while remaining unaware of the samples being tested. Quality control estimations were performed to ensure that all correctly sized debris objects along a transect were documented before a subsequent evaluator distributed the debris collection. A well-trained field assistant assessed about 20% of the total number of quadrants sampled per site throughout the study to ensure the sampling points were the same throughout the two seasons of data collection. Marine debris was determined and classified into plastics, metal, glass, rubber, processed lumber, and clothes and fabrics. All litter were counted on the site and recorded. Repeated measurements of standing stocks at the beaches reflected the gradual accumulation of long-lasting debris rather than providing an index of changes in the abundance of debris at sea. Finally, we collected comparative data by comparing information from various sources. A comparative data collection was conducted by analysing data from multiple locations to draw comparisons.

Citizen science perspective on marine debris

Purposive sampling was employed to choose the 171 respondents who took the survey (Table 1). Their selection was based on their experiences with the study locations and their willingness to participate in the survey. The survey was completed by tourism operators N= (1*3), traditional leaders, N= (1*3) revellers N= (15*3), fishermen N = (15*3 person/community) and fishmongers N = (15*3 person/community). Households in the proximity to the beaches were also considered; thus, N = (10*3) household heads were selected from the three communities to respond. A focus group discussion and unstructured interviews were the primary data collection modes for the study's citizen science dimension. The focus group discussion was used for the tourism operators, traditional leaders, fishermen, fishmongers, and household heads. Based on their availability, which would not favour the focus group, unstructured interviews were used for revellers.

Data analysis

After the classification and quantification of marine debris, the count represented the data for this study phase. Statistical analysis was employed to analyze the data, emphasizing frequencies, means, and standard deviations, and inferential statistics highlighting paired samples t-test and one-way analysis of variance. To investigate the differences in marine debris concentrations between the wet and dry seasons, the paired samples t-test was applied. The one-way analysis of variance explored differences in counts between the three study sites. Qualitative research of interview transcripts was conducted in NVivo for the citizen science data.

Limitations of the study

The study encountered some challenges during its course. One prominent limitation was the inability of the researcher to collect data from the surface of the water. The study focused solely on the beachfront area between the low tide mark and the zone of emergent vegetation.

Table.1 Composition of the respondents

Respondents' role	Sample size	Frequency (%)
Tourism Operators	3	1.8
Traditional Leaders	3	1.8
Revellers	45	26.3
Fishermen	45	26.3
Fishmongers	45	26.3
Household heads	30	17.5
Total	171	100

Another challenge was the inability to measure the weight of the debris. Although the weight of the debris was not measured, this is consistent with other studies that have only considered the headcount of the debris. Despite these setbacks, the results presented in this research are valuable for policy and practice. It has provided empirical data on marine debris along the coastline of the municipality. The study focused only on macro-objects, excluding micro-objects (⩽3 cm).

RESULTS AND DISCUSSION

This section of the paper presents the results and discussions. It is written in consonance with the objectives that guided the study. Attempts have been made to relate the findings to existing scholarly research.

Quantification and abundance of marine debris in Mfantseman Municipality

Throughout the study, 7589 marine debris were identified from Abandze,7906 from Anomabo, and 5249 from Biriwa beaches, amounting to 20744 debris items (Fig. 2). This presupposes that among the studied sites, Biriwa is the cleanest despite the tendency to interact with the other two areas. Of these, 10323 debris items were plastics, constituting 52.2% of all marine debris sampled. In Abandze, 3808 plastic items were recorded; in Anomabo, 4285 plastic pieces were identified, while in Biriwa, just 2730 plastic items were. Thus, the mean counts of 127, 142, and 91 plastic debris during the one year of debris collection for Abandze, Anomabo, and Biriwa. The average of plastics sampled for all 90 quadrants during the survey period ranged between 91 and 143 plastic debris counts.

Often confused for plastics, the rubber composition of the total marine debris comprised 2140 items (10.3%); thus, the mean count is between 11 and 16 items. Similar data were published by Allsopp et al. (2006), who claimed that plastics constitute the dominant source of marine debris globally, accounting for 60-80% of trash collected. Materials from plastic prevailed in most litter categories, as evidenced by most works on Ghanaian beaches. Nunoo and Quayson (2003), for example, accounted for 51.2% and 46.0% of the total at the Sakumono and Mensah Guinea beaches in Ghana, respectively. Yu (2023) discovered that plastics represented 63.7% of the content of marine trash. Beachfront surveys can determine the distribution and variability of litter volume and variety through aggregation geographic and chronological beach surveillance (Rees and Pond, 1995; Kusui and Noda, 2003; Edyvane et al., 2004; Oigman-Pszczol and Creed, 2007). Beach litter studies have been carried out all over the world to comprehend the forms and distribution of marine debris (Golik and Gertner, 1992; Velander and Mocogni, 1998; Kusui and Noda, 2003; Basterretxea et al., 2007; Santos et al., 2009; and Lee et al., 2015).

The mean number of clothes and fabric materials ranged between 27.8 and 43.6 during the survey period, so within a year, we found 3356 clothes and fabrics on the beaches. At the beach of Abandze, the recorded total count of textiles was 1308, while at Anomabo and Biriwa beaches, it was lower (1215 and 833 items, respectively), and 16.2% of the actual marine debris was textile across quadrants and sites.

The metallic materials, per the classification method adopted, constituted metal fragments, aerosol cans, aluminium and other tins and cans. They constituted 7.8% of the total debris, with an individual item count of 1624 during the survey.

The study also discovered that the total quantity of marine debris comprised of glass pieces constituted 1254 items, accounting for just 6% of all trash collected across all three studied beaches. This expresses a material class's most minuscule contribution to the total debris composition. For example, in Abandze Beach, 482 glass debris were recorded, with an average of 16 glass items during the survey. At Anomabo, 446 glass pieces were observed, with a mean count of 14.8 glass items also during the survey. Keeping the last record for glass, the quadrants at Biriwa identified a total count of 326, expressing a mean count of about 11 glass debris along the shore during the survey. The study attributes this observation to the higher density of glass materials compared to debris materials such as wood, plastics, fabrics, and rubber. Though the weight was not measured,

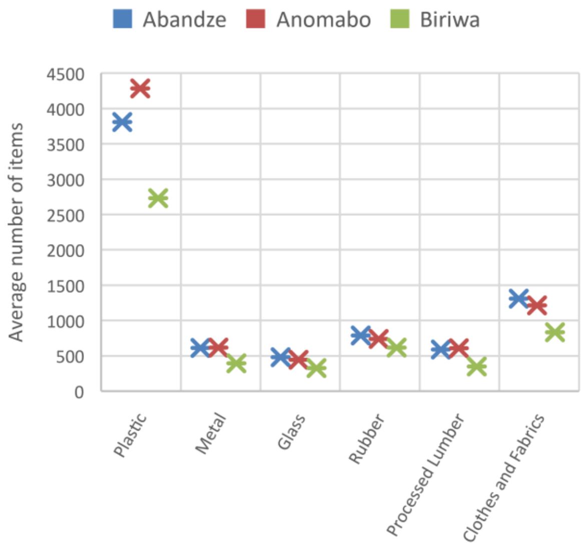

Fig.2 Abundance of marine debris in the studied beaches during a year

the size and weight of glass were higher as compared to plastics, clothes and other materials that may constitute marine debris.

The processed lumber, which features objects such as cardboard cartons, paper bags, paper and cardboard, wood and relevant building materials as per the NOAA classification, identified a total count of 1547 items, making 7.5% of all debris collected. In Abandze Beach, 590 lumber pieces were identified during the survey (an average of 19.6 lumber/location or quadrant). At Anomabo Beach, the highest number of lumber fragments were found (in a total of 606 with a mean of 20 debris surveyed, whereas at Biriwa, only 351 lumber items were identified during the survey period, which meant 12 items during the survey period.

Spatio-temporal and statistical differences in marine debris abundance

According to the available research, seasons influence marine debris concentration on beaches. Based on investigations such as Rees and Pond (1995), Kusui and Noda (2003), Edyvane et al. (2004), and Oigman-Pszczol and Creed (2007), marine debris dumping on the beach may be both a temporal and spatial variable and improved awareness of this variance can be highly beneficial to establishing suitable litter elimination measures.

Thus, within the presented study, the seasonality of debris abundance was also considered (Fig. 3). During the wet season, higher debris abundance was observed than during the dry season. During the entire length of the wet season, 11,177 debris items were identified, much more than during the dry season (9,567 debris items). The beach at Abandze kept the highest record of debris with 3758 debris items during the wet season, and Anomabo dominated the dry season with a 4168 debris item count. The physical qualities of the shore, distance to sources, weather conditions emphasizing rainfall, and currents and tides all influence the accumulation and number of marine debris (Carson, 2013). The morphological characteristics of the shore and the morphodynamics of beaches are also practical concerns. Wind speed/direction, precipitation, and marine debris density have all been determined to have a statistically significant association (Ertaş, 2021).

The maximum abundance of debris was found on Mediterranean Sea beaches in summer (Collignon et al., 2012; 2014), similar to the findings of this study, as at the studied beaches, the debris had a higher amount in the wet season. However, Ertaş (2020) presented the most substantial count of debris by quantity in spring, which coincided with the shift in time in our study area from the dry season to the rainy season. According to Ertaş (2021), the sampling period was April 2020, when the beach was extensively used for vigorous fishing and picnic activities, justifying the spring abundance.

The independent samples t-test was employed in the study to investigate the statistical differences in marine debris collected throughout the wet and dry seasons.

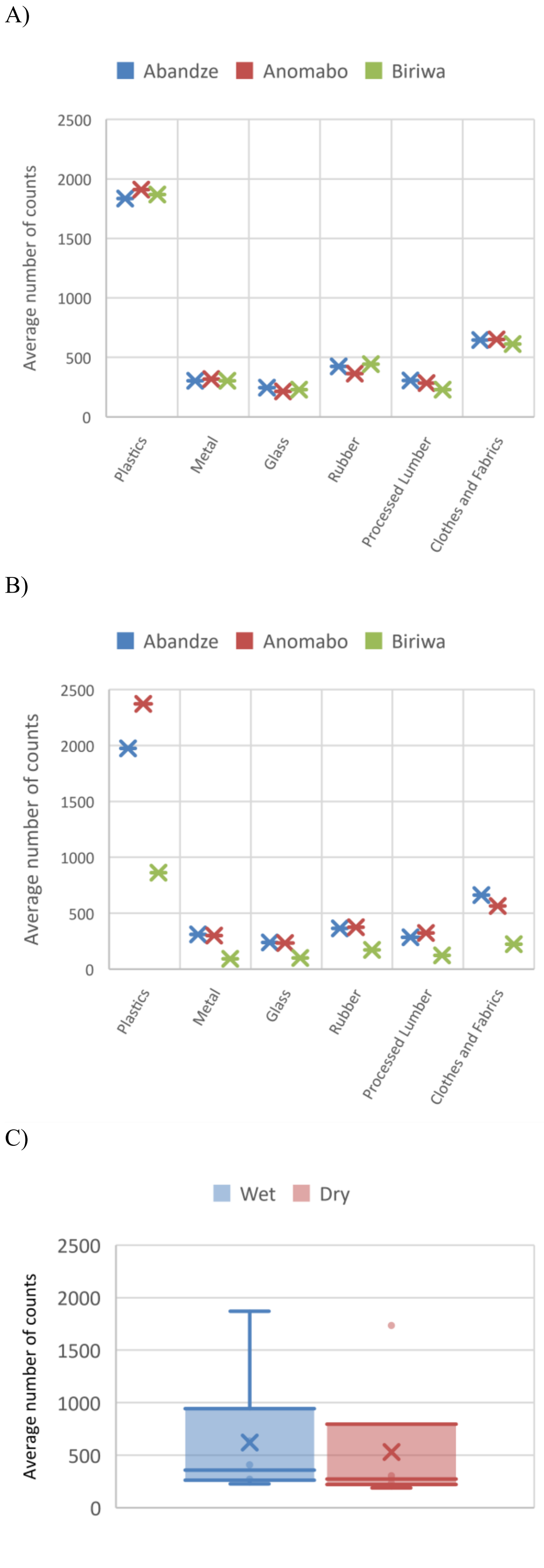

Fig.3 Spatio-temporal abundance of marine debris during the wet (A) and dry (B) seasons. C) comparative analysis of the spatio-temporal abundance of marine debris during the two seasons

The study revealed no statistically significant differences (t (58.05) = 0.89; p = 0.37) between the count of plastic debris for the wet (M = 5.67; SD = 0.99) and dry season (M = 5.32; SD 2.45), as it has been presented in Table 6. The case found for processed lumber also identified no statistically significant differences (t (76.81) = 1.24, p = 0.22) between the wet (M = 4.54; SD = 1.48) and dry seasons' (M = 4.05; SD = 2.22) concentrations (Fig. 4).

The case for metal, glass, rubber, clothes and fabric debris revealed no significant differences between the wet and dry season concentrations. For metals, the independent samples t-test returned a t (71.59) = 3.06, p = 0.00 between the wet season's count of metal debris (M = 5.13; SD = 1.39) and the dry season's (M 3.89; SD = 2.35). A t (67.67) = 2.45, p = 0.02 was established between the wet season's concentration of the glass constituents of marine debris (M = 3.81; SD = 0.84) and the dry season's (M = 3.16; SD = 1.55). For rubber compositions, a t (78.31) = 4.06, p = 0.00 was found between the wet (M = 4.55; SD = 1.1) and the dry seasons (M = 3.38; SD = 1.59). In consideration of clothes and fabrics, the independent samples t-test returned a t (59.73) = 3.68, p = 0.00 between the wet season's (M = 5.3; SD = 0.93) concentration and the dry season's (M = 4.02; SD = 2.14).

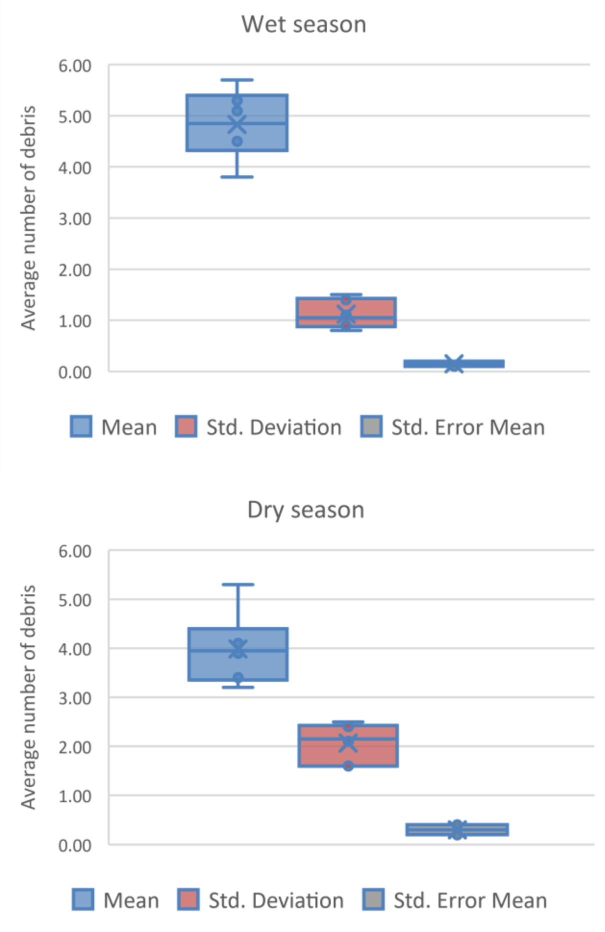

Fig.4 Paired sample statistics

Despite significant differences in seasonal counts of metals, glasses, rubbers, clothes and fabrics, the study revealed that only the differences in rubber concentrations found a large effect size (Fig. 5). A widely accepted convention is to classify effect sizes as small (d = 0.2), medium (d = 0.5), and large (d = 0.8) according to benchmarks proposed by Cohen (1990). The magnitude of the differences in means for metals was moderate (eta squared = 0.09) with a mean difference (MD) = 1.24, 95% CI: 0.43 to 2.05. The magnitude of the difference in glass concentrations also observed a moderate effect size (eta squared = 0.06; MD = 0.64; 95% CI: 0.12 to 1.17). Being the only debris class to observe a large effect size (eta squared = 0.15), rubber debris kept a mean difference (MD) of 1.17 at a 95% confidence interval with lower and upper limits of 0.6 to 1.74. The effect size for clothes and fabrics was identified as an almost large effect size, according to Cohen (1990). The results established an eta-squared statistic of 0.13 for a mean difference of 1.28 at a 95% confidence interval of 0.58 to 1.97. This finding is based on the benchmarks proposed by (Cohen, 1990) based on the classification of the size of the debris collected and counted.

Having established the statistical differences in the temporal occurrence of marine debris on the studied beaches, the findings conform with establishments according to relevant literature. Ertas (2021) discovered that litter density differed considerably between seasons in a similar context on Turkey's Homa Lagoon Coast (one-way ANOVA, P0.05; F (7.21) = 2.03, P= 0.0015). According to the study, beach litter was distributed unevenly; litter density was substantially higher in summer than in autumn, winter and spring (t-test, P0.05). This finding, as has also been found by the current study, has not been established by chance or coincidence but is scientifically justifiable because, during the wet season, debris transport by run-off and rivers is active and more pronounced than in the dry season.

A one-way analysis of variance (ANOVA) was used to examine the statistical differences in the count of marine debris for the three study sites. ANOVA was motivated by the fact that three locations were compared, which could not be accomplished with the t-test used to investigate the season debris count. According to Pallant (2020), one-way ANOVA is used when one independent variable has three or more levels. The Welch test is reported after violating the assumption of the homogeneity of variances for all debris classes except for processed lumber. Welbourne and Grant (2016) aver that the Welch test is more powerful and maintains alpha at its desired level, recommending it for regular reporting of ANOVA results.

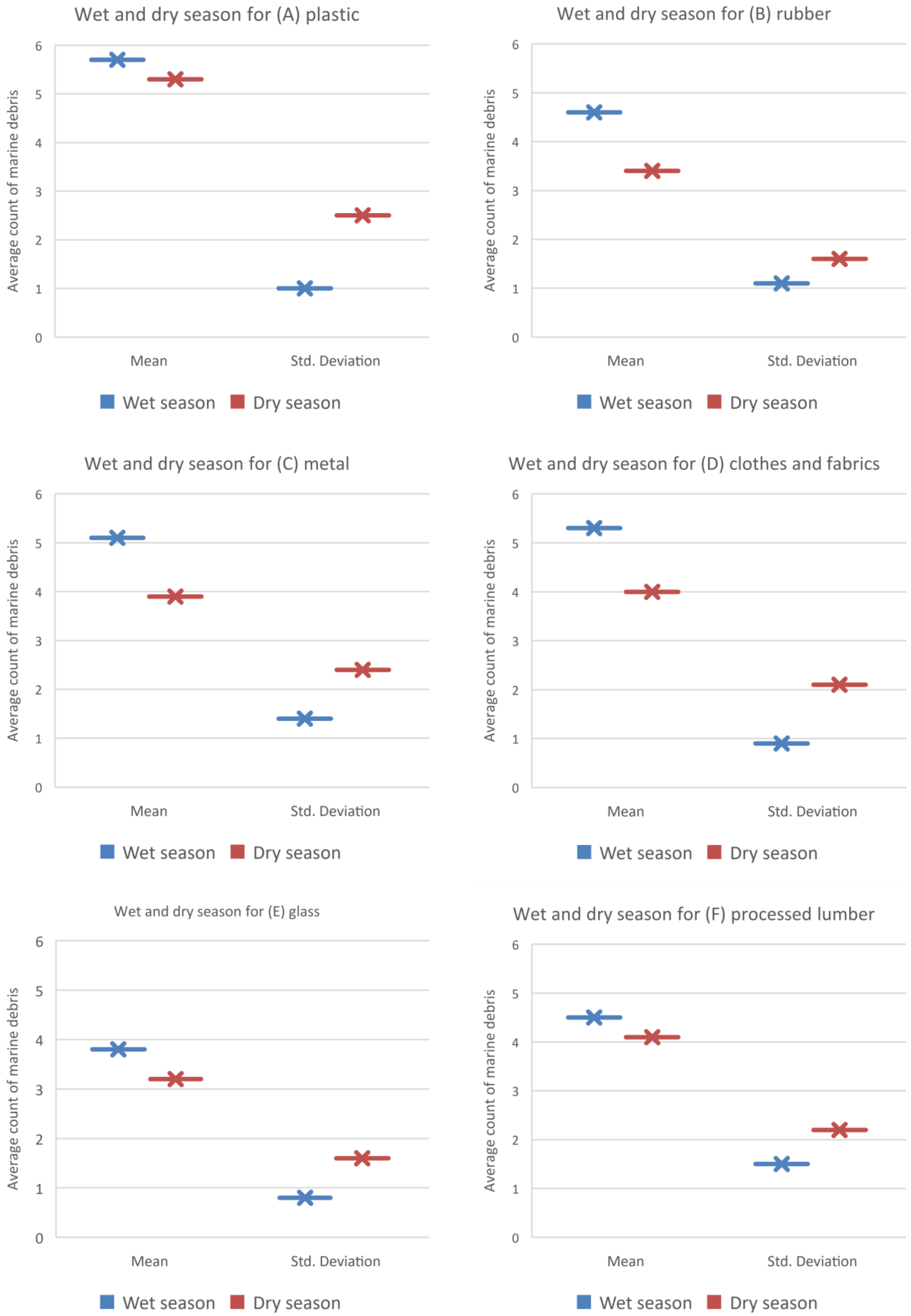

Fig.5 Mean and standard deviation of paired samples in the wet and dry seasons for (A) plastic, (B) rubber, (C) metal, (D) clothes and fabrics, (E) glass, (F) composite marine debris count for the two seasons.

Statistically significant differences were identified in the quantities of all debris categories across all study locations (Fig. 6–9) in different analyses. For plastics, at a $p < 0.05$, the count of debris at the three study sites significantly varied ($p = 0.00$) from one another: F (2, 44.36) = 18.29. According to Cohen's (1990) classification, a large effect size expressed by an eta-squared statistic of 0.29 was established for the differences in plastic concentrations for the study sites. For metal debris, a significant difference ($p = 0.00$) was found between the three study sites as F (2, 55.97) = 10.009 was found. Also, a large effect size (eta squared = 0.18) was established for this difference. In the case of glass, a significant difference ($p = 0.00$) has been shown between the three study sites on finding F (2, 54.64) = 10.19. A vital effect size (eta squared = 1.89) has also been established for this difference. The case found for the rubber class of debris identifies a minimal effect size (eta squared = 0.07) despite a statistically significant difference ($p = 0.03$; F (2,55.71) = 3.52) has been found between the count of rubber debris for the three study sites. Processed lumber materials which were found on the three study sites significantly differ in terms of counts as a $p = 0.00$ with F (2, 87) = 15.803 were found. A significant effect size supports this difference with an eta-squared statistic of 0.26. Lastly, a statistically significant difference ($p = 0.00$) was established for clothes and fabric debris collected from the three study sites: F (2, 52.699) = 13.728). A large effect size supported by an eta-squared statistic of 0.25 was found for the case.

The post hoc comparisons of study sites using the Tukey HSD test were also performed (Fig. 7), reflecting significant differences in plastic debris between the two pairs of study sites. In essence, the beaches of Abandze and Biriwa and Anomabo and Biriwa significantly differed in the compositions of plastic debris collected from there. This connotes that there was no significant difference between Abandze and Anomabo. There were statistically significant differences in the debris count in the metal class between Abandze and Biriwa and between Anomabo and Biriwa.

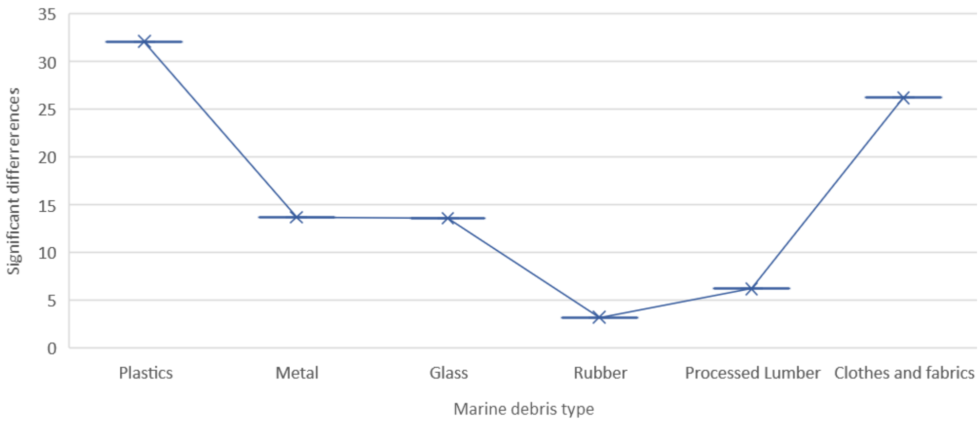

Fig.6 Paired samples test

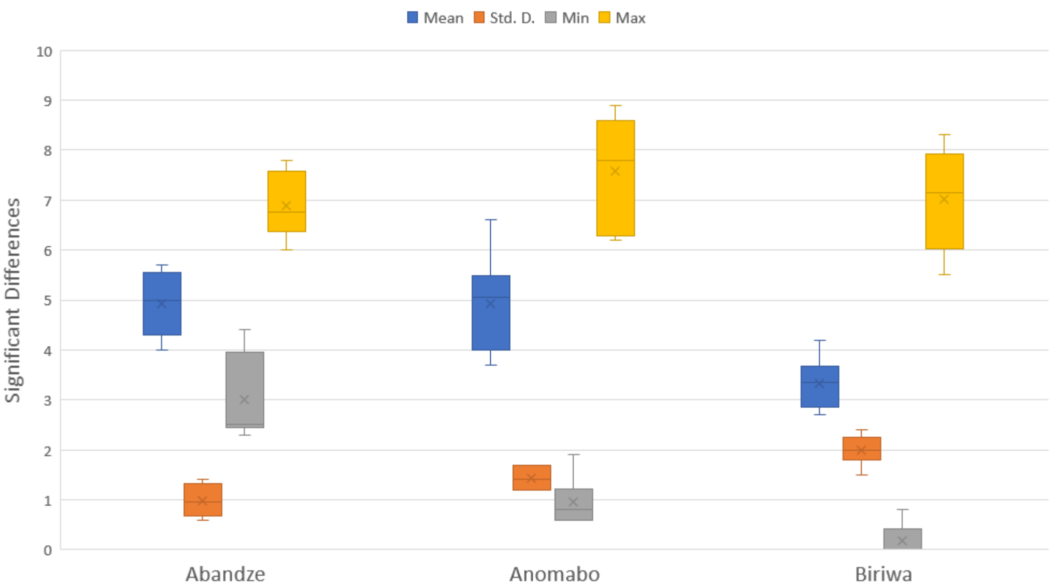

Fig.7 Independent samples test

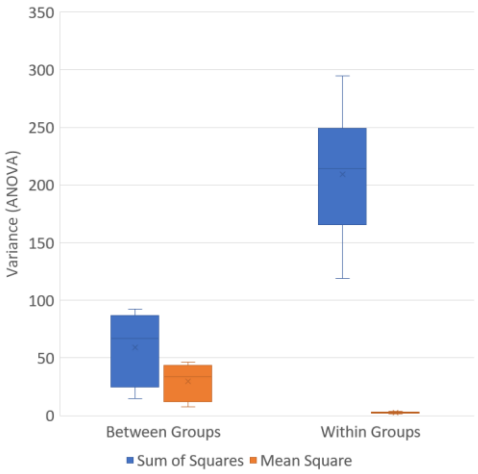

Fig.8 Analysis of variance (ANOVA)

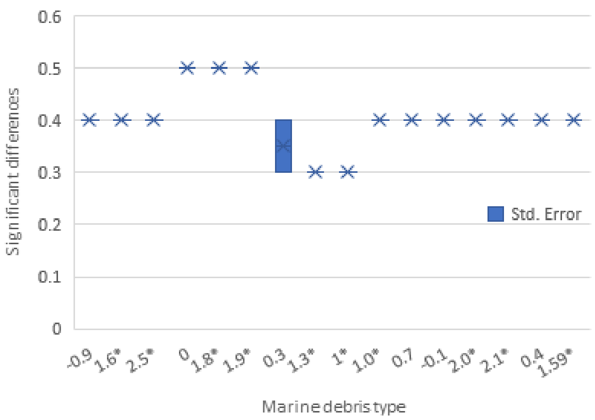

Fig.9 Post hoc with Tukey HSD

This is to emphasize that no significant difference was observed between Abandze and Anomabo for metal debris, similar to glass debris. Between Anomabo and Biriwa and Abandze and Biriwa, a statistically significant difference was observed in the count of glasses collected (Fig. 7). Rubber concentrations at Abandze and Anomabo were also not significantly different. However, statistically significant differences were observed between Abandze and Biriwa and between Anomabo and Biriwa.

Similarly, processed lumber debris observed no significant differences between Abandze and Anomabo but between Abandze and Biriwa and Anomabo and Biriwa. Lastly, Abandze and Anomabo found no significant differences in clothes and fabric debris count (Fig. 9). However, Abandze and Biriwa, and Anomabo and Biriwa, like found for all other debris classes, found statistically significant differences in the count of clothes and fabrics debris.

Significant disparities in debris accumulation between study locations are consistent with the findings of Ertaş (2021), who found that station-based assessments revealed that some stations had more litter accumulation than others. The results of this study show that the count of marine debris collected from Abandze does not differ from that of Anomabo. Still, significant differences exist between Abandze and Biriwa and between Anomabo and Biriwa, implying similarities in Abandze and Anomabo that differ from Biriwa.

Citizen science approach: Socio-demographics of respondents

The study included 171 respondents who completed a questionnaire with a response rate of 100%. The age of most responders (41.5%) was between 18 and 28 years (Fig. 10). Almost one-third of them (35%) were between 29 and 39 years old, and only 4.6% of the total sample were aged over 50 years.

There was a significant discrepancy in the number of males and females participating in this poll, as males comprised almost 60% of the total respondents. The results revealed that 32.7% of the respondents earn 51.8–66.6 USD. An appreciable number of respondents (22.8%) did not declare their monthly income, and 8.8% earned less than 22.2 USD/month. After analyzing the data regarding the average monthly income of the respondents, it appears that a significant portion of them fall under the category of poor. In 2022, the daily minimum wage in Ghana was ¢13.53, which is almost equivalent to one USD per day. Given this comparison, it is clear that the respondents' monthly income falls below the poverty line and are likely to interact more with the coastal environment for marine resources.

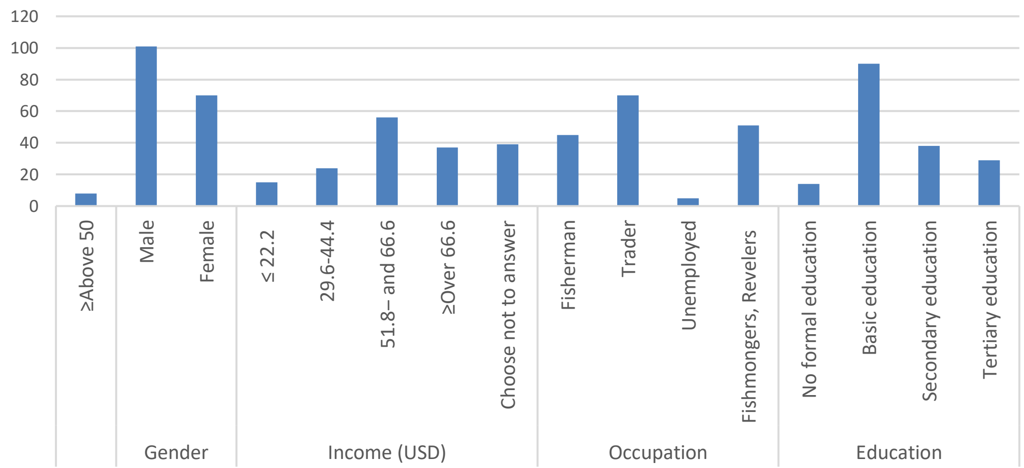

Fig.10 Socio-demographic characteristics of respondents

Regarding the educational levels of respondents, the study identified that a few of the respondents (8.2%) had no formal education, and the majority (52.6%) expressed that they had up to basic school level. Most respondents (40.9%) were found to be traders; 26.3% were engaged in fishing, and 2.9% were unemployed.

Citizen science perspective on types and sources of marine debris

Knowledge of the source of litter will determine what people believe about the garbage surrounding them. This local knowledge will inform environmental managers on how to approach debris accumulation mitigation, especially with approaches targeting the local release of litter. Figures 11 and 12 show some of the ocean and land-based debris identified along the coastline of the study areas.

The locals, 168 (98%) believed that land-based debris was the dominant debris type they observed on the studied beaches, while only 3(2%) were of the contrary view. Land-based debris that respondents have ever kept on the shores include plastic bottles, plastic straws, black/white plastic bags, plastic cups and lids, glass bottles, water sachet, balloons, metallic tins and cans, cigarette packaging/wrappers and butts, corks, disposable plates and spoons, kebab sticks, pieces of cigarettes, footwear pieces and flip-flops, clothing/textile. According to the respondents, land-based debris was the most prevalent source of trash discovered on the beach. Because the research region is close to settlements, respondents (83%) predicted that drains and outfalls would result in more rubbish being swept into gutters and deposited onto the coastline. According to 48% of those polled, beachgoers are the most significant source of waste on the beach, and 45% believe that refuse from various dwellings contributes to marine debris collection on beaches. Only 3% attributed debris sources to boats/ships, 2% and 2% to stormwater discharge and other activities, respectively.

Because of the development of artificial substances such as plastics during the last 40 years, the nature of trash in humanity has altered dramatically. Plastic is a long-lasting substance that is not impacted by natural decomposition mechanisms. This explains why participants listed plastics as the most prevalent type of beach litter. When plastic debris hits the water, approximately half of it floats, and it can be transported by bony waves and currents thousands of miles away and becomes extensively scattered over the oceans (Sheavly, 2005). Based on this, the current study positions that debris observed by respondents has not been generated in the settlements adjoining the studied beaches. This highlights that the collected debris originated locally and did not drift from other regions. However, as Sheavly (2005) identified, it might have originated at a further distance from the coast, away from the marine environment. The high number of plastics counts observed at the beaches agrees with a Ghanaian study by Nunoo and Quayson (2003), who also found the dominance of plastics on two beaches of Ghana (Sakumono and Mensah), where 51.2% and 46.0% of total debris composition were plastics. The prevalence of plastic-based products underscores Ghanaians' widespread adoption of plastics in every aspect of their lives.

According to Kako et al. (2010), beach trash does not remain the same throughout the coastline but changes periodically with re-drifting from the beach to the oceans. Debris is washed offshore by nearshore hydrological dynamics such as wave setting and near-shore currents (Kataoka et al., 2013, 2018). Due to this backwash process, beaches become recipients of marine debris and secondary generators of marine debris in the marine environment. This is congruent with research on various Ghanaian beaches (e.g. Mensah Guinea, Sakumono) (Dodzi Dzitse, 2021), and correlates with the assumption that land-based sources contribute around 80% of the marine debris on our beaches (Sheavly and Register, 2007).

As revealed by all respondents, high volume of

Fig.11 Marine debris found along Abandze beach

Fig.12 Land-based type of marine debris found along Abandze beach

land-based debris at the study site can be attributed to some factors like the beach location and accessibility by local people and tourists (beachgoers). It is reasoned by the fact, that litter items like plastic bottles and bags, metal cans are clearly associated with and indicative of beach users as attributed by (Al-Najjar and Al-Shiyab, 2011).

Participants (100%) in the study agreed that marine trash is a severe problem. The outcomes show that human behavior is the underlying source of marine waste, as evidenced by the public opinion survey. Most respondents admitted to being responsible for beach dumping waste, which was apparent at the beaches investigated.

Beach users were recognized by 126 (73%) of the respondents as the leading source of litter production on the beach due to unappealing beaches. Also, a significant number of respondents (23%) believed that beaches in the study areas are unclean, and the number of debris there keeps increasing due to the failure of the authorities and the community members to protect the beauty and integrity of the beaches. This gives users a cause for concern despite their role in litter generation. The data show that respondents 154 (90%) were not in the routine of picking up rubbish. This was due to their misconception that collecting was the duty of the local assembly and Zoomlion, a waste collection company in Ghana. Only 10% of the respondents believed that plastic waste should be collected. One of the owners of a resort at the beach said that "collection of litter disposed at the beach is the responsibility of the Municipal Assembly and Zoomlion Company."

The study discovered that garbage is a big issue for beachgoers and is integral to choosing an appropriate beach for pleasure. Participants (95.9%) believed that beach litter is a problem, and many beach users/tourists consider it when choosing a convenient place for recreation. At the same time, 3 (1.8%) disagreed with such assertion. Four of the respondents representing (2.3%) were undecided. This trend is supported by Lewin (2019) and also following findings by Santos et al. (2009) cited in Slavin (2011), who contend beach contamination by debris has an implication on tourism and thus economic gains and also affects beach choice and recreational activities. This, in a way, poses a severe threat to coastal economies by repelling visitors and income from tourism, besides damaging marine life and the transfer of invasive species.

Citizen science perspective on the effects of marine debris on coastal communities

Marine debris has far-reaching and largely negative consequences, generating financial damages in commercial fishing, recreation, and tourism areas. This study found that survey participants 169 (98.8%) were aware of some of the issues caused by marine debris (Fig. 13). Almost all respondents, 169 (98.8%), knew of at least one case that marine debris could cause; yet, surprisingly, they all admitted to having littered before. Two of the respondents were skeptical about the incidence of marine debris in the study area.

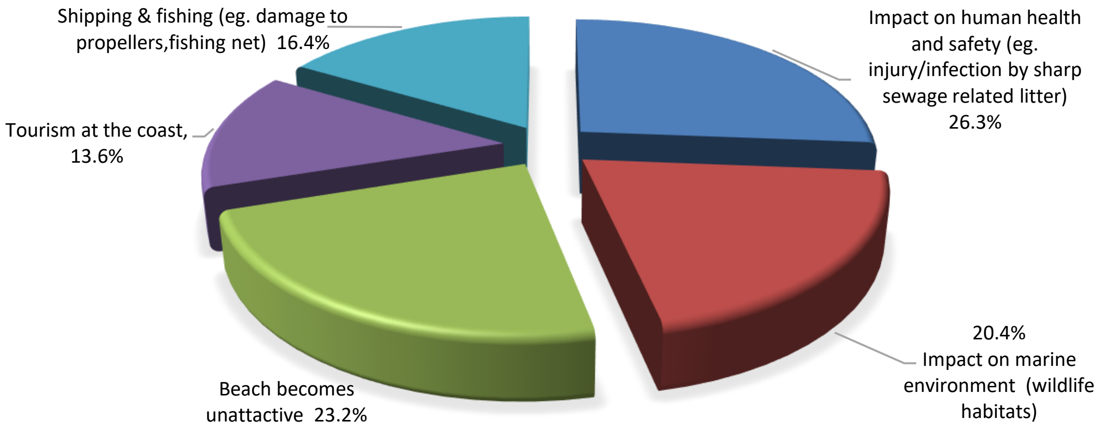

Fig.13 Effects of marine debris on coastal communities based on a citizen's survey

Almost one quarter (26.3%) of the respondents believed that marine debris affects human health and safety, leading to injury/infection caused mainly by sharp sewage-related litter. Marine debris poses a potential threat to human health. Sharp or hazardous debris can cause injuries to people while swimming or playing in the water. Additionally, the seafood we consume may contain plastic particles. Despite this, the health implications of various plastics and chemicals to humans are not yet fully understood. Another (13.6%) also indicated that it affects tourism around the coast as the beach's aesthetic nature is primarily affected, decreasing attendance or motivation for revellers to visit such destinations. Marine debris can have a negative impact on our economy. Unclean beaches can affect tourism and recreation, which is usually the biggest employer in most coastal economies. This industry heavily relies on healthy coastal and ocean resources, as well as the aesthetic quality of the environment. A study has shown that people's choice of destination is greatly influenced by the visual appeal and peace of mind offered by the environment. This means that most individuals will avoid venues with a high accumulation of debris.

The respondents (20.4%) also mentioned the harmful impact on the marine environment. In the marine environment, aquatic resources are affected, and their habitat is polluted. Marine debris can harm wildlife by being ingested. Animals may swallow debris, which can result in stomach blockages, punctured internal organs, and a false sense of fullness. This can cause the animal to become ill or starve. Some animals, like turtles, may mistake plastic bags or balloons for their prey. As plastic debris breaks down into smaller pieces, it becomes easier for smaller creatures such as zooplankton to consume. Other effects were beaches becoming unattractive (23.2%) and shipping and fishing being affected (16.4%). Vessels left abandoned and derelict, along with other forms of debris, can have detrimental effects on marine life and those operating watercraft. Sunken boats can prove difficult to detect in waterways, increasing the risk of collisions and damage to other vessels. Furthermore, the presence of larger debris, such as discarded fishing gear, vessels, and appliances, can lead to the destruction of delicate habitats like coral reefs. Several respondents 164 (95.9%) declared that they had suffered some problems associated with litter on the beach. The majority of them 132 (80.5%) indicated that they feel some level of discomfort with the mere occurrence of debris on the beaches, with others 32 (19.5%) attributing pain to the possibility of wounds and diseases resulting from marine debris.

These findings support the claim of Mouat et al. (2010) that marine trash lowers individual living standards by reducing recreational options and aesthetic value and raising various safety and well-being concerns. In support, Allsopp et al. (2008) provided proof that marine debris impacts the marine environment, as it influences around 86% of all sea turtle species, 44% of all sea bird species, and 43% of all aquatic species of mammals. Solid particles ingested by fauna are excreted; however, undigested particles may remain in stomachs, including seafood (Rochman et al., 2015).

Agamuthu et al. (2019) have identified three main categories of the impacts of marine debris, namely: injury or death of marine organisms, harm to the marine environment, and effects on human health and the economy. According to Agamuthu et al. (2019), marine mammals are particularly vulnerable to accidentally ingesting marine debris as it often looks like food. The coastal landscape often suffers from marine litter, which damages recreational activities and reduces tourism value (Galgani et al., 2021). Marine litter can have economic impacts on maritime industries, such as fisheries and aquaculture (UNEP, 2014). Lusher et al. (2018) argue that discarded fishing gear poses a significant threat to air-breathing marine animals, including endangered species that may become entangled in the nets either intentionally or accidentally.

CONCLUSIONS AND RECOMMENDATIONS

The study has established that all the classes of marine debris, according to the NOAA marine debris classification, occur on the beaches of the studied coastlines. The types of debris were plastics, metal, glass, rubber, processed lumber, clothes and fabrics. It was revealed that almost all had land-based source. The accumulation of marine debris in a certain area is mainly caused by human activities, such as settlement and tourism. The geographical location and shape of the beaches also play an important role. If the topography is flat, the debris is likely to accumulate. Additionally, rivers and streams can transport debris from nearby communities and deposit it on the beach and this is exactly the case in the study area. The study found the dominance of plastics in the composition of debris. The study also found significant variations in marine debris occurrence between the wet and dry seasons and between the towns whose beaches have been studied. Coastal communities regard marine debris as a problem of concern, as it was made known that beach users and tourists consider it before selecting a suitable place for recreation. Also, its presence affects tourism income, human health (injury, discomfort and wounds), and even marine habitats. The paper analyzes the correlation between marine debris and socioeconomic factors such as gender, age, education, tourism, and monthly income. It also explores how income can mitigate the impact of marine debris. The findings suggest that marine debris tends to increase with income, but it starts to decline at higher income levels. The study revealed that most of the respondents had limited income, which led to an increase in debris generation. The Mfantseman Municipal Assembly has identified waste management as one of their primary challenges. The paper argues that understanding the socioeconomic factors related to marine debris is crucial in developing effective policies and allocating resources to address the issue of marine pollution.

Based on the findings, the study recommends that adequate assemblage, disposal and treatment infrastructures should be provided by the authority, in essence, the local government assemblies through the waste management departments of the communities and private waste management contractors. Intensive education and sensitization remain critical in reducing marine debris on Ghana's shores. One effective way to address the issue of marine debris pollution is by focusing on preventing it at the source and educating people about its impact. By investing in prevention and education, we can reduce the harm caused by marine debris to marine life and their habitats. This approach is not only cost-effective but also provides greater flexibility and long-term success in conservation efforts. The Municipal Assembly should establish plans for educational and public awareness campaigns (using brochures, flyers, stickers, and posters) aimed at eliminating all litter and targeting users of the maritime environment, and locals utilizing resources. That is, residents of nearby communities and revelers who visit the beaches should be sensitized on the need to keep the environment clean by stopping littering, as this directly ends up as marine debris on beaches and in the ocean water column. The local government assembly, in collaboration with waste management companies (e.g. Zoomlion Ghana Company Limited), should provide waste collection bins which will aid in limiting littering in the adjoining communities. Furthermore, the municipal assembly should implement year-round beach clean-up exercises. Currently, beach clean-ups and surveillance are conducted on more frequented beaches (urban and semi-urban beaches by NGOs and Clubs), which can work in the studied region as well. The paper contributes to the understanding of the interconnection between humans and the environment by articulating that marine debris has a negative impact on all the values associated with the coastline, such as its beauty and rich biodiversity. Plastic debris poses a threat to marine species as it can be ingested or can entangle, causing severe harm and even death. Moreover, plastic pollution can affect food safety and quality, human health, and coastal tourism while also contributing to climate change. The information presented in the paper can help us better understand how changes in the coastal environment affect us. The research has shown that the effects of marine litter, especially macro and microplastics, on human health are still a topic of debate. To address this issue effectively, more in-depth and comprehensive research needs to be conducted on the beaches of Ghana and around the world.

Conflict of Interest: I certify that I have no affiliations with or involvement in any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript.

Data Availability: The datasets generated during the study are available upon request from the corresponding author.

Declarations
Competing interests: The author declares no competing interests.
Ethical Approval: Approval was obtained from the corresponding author institution's Ethical Review Board (ERB) that the procedures used in this study adhere to the tenets of the Declaration of Helsinki.
Informed consent: All participants and their legal guardians had written informed permission before the interviews.

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